The Electrical Conductivity of Bacteria, and the Rate of Sterilisation of Bacteria by Electric Currents.

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1. *Introduction.*

Electrical currents, both alternating and direct, retard the growth of bacteria in liquids through which they are passed, and under certain conditions cause complete sterilisation. The cell-contents are coagulated by the heat generated, or by electrolytic effects within or without the cell. There is the further possibility that protoplasm may be disintegrated by the mechanical action of an alternating current upon molecular charges, similar in effect to that of rapid vibration, which is known to check the growth of, and even to kill, bacteria. Whether the retardation of growth is regarded as the result of changes in the cell or liquid, the effect is largely controlled by the relation between their electrical conductivities. When these are the same the current flows as if the cell were not present, otherwise the current-density in the bacteria is greater or less than that in the liquid, according as their conductivity is respectively the greater or less. In order, therefore, to control effectively the bactericidal action of electrical currents in a liquid, the relative conductivities of the liquid and the contained bacteria should be known. A full summary of the industrial applications of electrical currents in organic processes is contained in Lafar's 'Technisches Handbuch der Mykologie.'* In most of the cases referred to the currents were weak and the voltage gradients in the liquid low. The special feature of the present work is that the voltage and current were taken to their highest limit, under the condition that the temperature did not exceed 30° C., with the testing cell cooled by immersion in running water.

The 'Comptes Rendus' of April, 1896, contained a short account of observations by S. Lortet on the orientation of bacteria in water through which an alternating current was passed. It was stated that only living bacteria orientated, an observation which, if it had been confirmed, would have had bearing on the relation between electricity and life. This is, however, not the case, for bacteria which have been boiled for several hours orientate

* 1899, vol. 1, p. 455.

more freely than before. Lortet's observations would be at once explained if his emulsion had been sterilised by the addition of an ionising liquid, such as perchloride of mercury, the conductivity of which is greater than that of the germs. The fact is that dead or living bacteria orientate equally well.

[*April 24th.*—In this paper the cause of the observed orientation is considered to be the influence of the electric field upon charges induced on the surface of the bacteria. The surface density σ of charge on the interface between two media of resistivities ρ_1, ρ_2, and dielectric constants k_1, k_2, with a current density i normal to the surface, is given by the relation $4\pi\sigma = (k_1\rho_1 - k_2\rho_2)i$. Thus, when k is about 80, as for water, ρ 100 for saline solutions, and i 1 ampère per square centimetre, σ is of order unity.* This is comparable with the surface density on metallic conductors charged to several thousand volts in air, and is much greater than that on a surface between good conductors.

The dielectric constants of saline solutions have still to be experimentally determined; the product $k\rho$ can, however, be found from existing data in terms of the refractive index. The dispersion terms in the Helmholtz–Ketteler formula for the dispersion of light contain the number of electrons N in unit volume as a factor, and since electrical conductivity is also proportional to N, the sum of these terms can be written b/ρ in low frequency fields.

Thus when the formula is applied to solutions of varied conductivity $n^2 = k + b/\rho$, or $k\rho = n^2\rho - b$, n being the refractive index. From tabulated data† the conductivity of saline solutions is nearly proportional to the percentage g of added salt, and we may write $g\rho = a$, a constant. Schütt has shown‡ that for these solutions the change of refractive index is also proportional to the added salt, so that $(n-n_0)/g$ = a constant, c. Thus $\rho = ac/(n-n_0)$ and $k\rho = acn^2/(n-n_0) - b$.

The values of $n^2/(n-n_0)$ for different strengths of solution are as follows:—

g.	$n^2/(n-n_0)$.
1	1010
5	204
10	103
30	36

The product $k\rho$ therefore decreases as salt is added. In the expression for σ the current density is proportional to the strength of the solution, so

* See Jeans, 'Electricity and Magnetism,' p. 336.

† See Whetham, 'Theory of Solution,' p. 413.

‡ See Landolt and Börnstein, 'Tabellen,' p. 684.

that, on the whole, if the effect were determined by transfer across one surface only, σ should be higher in strong solutions. But, in the case of a freely suspended body, there will be no orientating couple when the conductivities of the liquid and body are the same, for the current flows through both at the same density everywhere. It is then reasonable to conclude that orientation ceases in a solution having the same conductivity as that of the contained bacteria.

It has been suggested that, since the observations of orientation had been made on thin layers of liquid, it might equally well be explained by electrical endosmose. This is to some extent met by the fact that orientation is quite as marked in deep hanging drops, and in cells several millimetres deep, filled with distilled water. Observations are difficult in these cases on account of continuous thermal streaming in the liquid. It can, however, be readily shown that endosmose is only of importance at low frequencies, and that at frequencies of several thousand a second it entirely disappears. Orientation was first observed in high frequency fields, and is quite different in character from the rigid oscillatory motion caused by endosmose at low frequencies. At 80 periods a second, vigorous movement of all floating matter was observed. Elongated particles instantly moved into line with the flow, and spherical particles, such as carmine, were carried to and fro with an amplitude of about two of their diameters, thus resembling short rods in the field of vision.

The characteristic feature of the effect was the extreme rapidity with which orientation took place. On substituting an induction coil, with a condenser across the hammer make and break, for the transformer previously used the effect entirely ceased, though the voltage across the drop was now about four times as high. Purified asbestos was then ground to such a degree of fineness that particles were just visible with a No. 4 ocular and 1/12 inch objective. These remained in perfect definition when the current from the induction coil was passed through the liquid. Bacteria which were almost invisible in low-frequency fields owing to the rapid oscillatory movement, remained in perfect definition in the coil current and were at the same time actively orientated.

It may then be said that the mechanical movement of the liquid as a whole under the cover-slip has an amplitude of less than microscopic dimensions at the frequency of the high-tension side of an induction coil, under a gradient of about 1000 volts per centimetre in the film.

As a further test, a strong emulsion of *B. coli communis* being under observation with many hundred slightly motile bacteria in view, the voltage from the coil was applied, and all were seen to be orientated. The primary

current was then gradually reduced and the control of the bacteria observed to be weaker, until a point was reached where, though the majority lay in the same direction, at least one-third did not appear to be under control. On raising the voltage all again came into line with the field.]

2. *Method of Measuring the Conductivity of Bacteria.*

From the nature of the case it would be very difficult, if not impossible, to measure the conductivity of bacteria at all accurately by any of the methods at present in use, for example, by passing a current through a fine tube filled with a paste of organisms. Since, however, there is no couple when the conductivities of a rod and the liquid around it are the same, it is only necessary to make trials in a series of liquids of gradually increasing or decreasing conductivity, and to note that in which a rod inclined to the field ceases to show orientation when the current is made or broken.

To make the measurements of resistance in the present case, a series of 12 solutions of sodium chloride in water was made ranging from 0·0016 to 0·04 grm. of salt per cubic centimetre, of which the corresponding conductivities were measured. A drop of the weakest of these was placed upon an ordinary glass microscope slide. To this was added a few bacteria from a pure culture, and a cover-slip dropped over it. The drop was large enough for liquid to exude from the edges of the slip to permit the introduction of platinum wires flat along the edges of the cover-slip in the liquid. The bacteria then being quickly under observation in the microscope, an alternating current was passed and any movement of orientation noted. When they turned into line with the field their conductivity was taken to be higher than that of the liquid. A fresh drop would then be taken from the next higher strength solution, or if the orientation was vigorous from the highest, and the process repeated until that solution was found in which the movement ceased. In the case of high-resistance bacteria a difference of 0·5 mgrm. of salt per cubic centimetre in the solution could be detected in this way.

In most of the experiments a small laboratory induction coil was used. The voltage between the platinum poles when the current was passing was at least 100, giving a gradient in the liquid of 50 volts per centimetre. This was sufficient to show orientation in distilled water. For demonstration it is more satisfactory to use a quarter inch spark induction coil, the voltage of which falls to a few thousand when connected across the drop.

The following table gives the results of the measurements on bacteria which are to be found commonly in water or milk. A few others are given of which there were active growths available at the time. The culture

medium is mentioned because of the great difference between cultures on or in different media, in the case of *B. typhosus*, for example.

The chief points established by the values found here are :—

(1) The electrical conductivity of any organism is not independent of the culture medium used.

(2) Bacteria which have their habitat in the animal have higher conductivities than those usually found external to it.

(3) The former have, on the whole, a higher conductivity than blood.

Table I.—Specific Resistances of Bacteria.

	Ohms per cm. cube.	Culture medium.
B. coli communis	140	Agar, rather dry.
„ from fresh sewage	82	Agar, moist.
„ „	60	Broth.
B. typhosus.....	250	Agar, from broth.
„	200	„ from agar.
„	105	Gelatine, from broth.
„	43	Agar.
„	120	Boiled 1 hour, 200 ohms before boiling.
„	35	Autoclaved 5 hrs., „
B. enteritidis sporogenes	200	Agar.
Sewage streptococcus	45	„
Proteus vulgaris	86	„
B. violaceus	340	„
Micrococcus prodigiosus	340	„
B. subtilis	350	„
B. anthracis	200	„
B. acidi lactici	200	„
„	80	Broth.

In order to see how this variation depended upon the resistances of the media themselves, the following measurements were made :—

Table II.—Specific Resistances of Culture Media, Milk, and Water

	Ohms per cm. cube.	
Nutrient beef agar.....	60—70	
Beef gelatine, 10 per cent.	115	
Turnip gelatine	275	
4 per cent. gelatine in water	290	
Broth	70—104	No two samples from different stocks the same.
Blood serum	96	Separated by standing.
Fresh blood	200	
Fibrin	245	

Table II—*continued.*

	Ohms. per cm. cube.	
Fresh milk, 1 to 2 hrs. after milking...	233	From different sources.
,, ,, ...	240	
,, ,, ...	252	
,, ,, ...	252	
Fresh cream	557	
Cream with acid reaction	480	
Separated milk	210	
Milk with slight acid reaction	196	
Sour milk	180	
Sour and semi-solid	169	
Tap-water, with bacteria added	1400	
Stream water	1300	
Town sewage	1250	

Comparing Tables I and II, it will be seen that *B. typhosus* from gelatine has practically the same conductivity as the culture medium, and that that on agar, though at first high, falls even below that of the medium, suggesting that there is marked absorption of conducting salts by organisms grown on agar.

3. *Influence of Sub-culturing on Conductivity.*

It was recognised from the above figures that, to obtain perfect comparison of the conductivities of various organisms, they should be taken from cultures, not only of the same age, but of the same order of sub-culture. An organism which has been many times sub-cultured could not in general be expected to have quite the same conductivity as one fresh from the animal. The following determinations were made to decide this point. The organism used was *B. coli communis* from house sewage, and the cultures were all in broth from the same stock :—

	Ohms per cm. cube.
Fresh from the animal	95—90
First sub-culture.....	60
Second ,, ...	45—40
Third ,, ...	40
Fourth ,, ...	35
Fifth ,, ...	35
Sixth ,, ...	35
Seventh ,, ...	35

There is, therefore, a rapid increase in conductivity due to the change of habitat from the body to broth. After the fourth sub-culture a steady state

is reached. The ratio of the specific resistance of the medium to that of the organism in broth, taking a mean value of 87 ohms per centimetre cube for the latter, is 87/35, that is 2·5. Taking the value for blood, which is also Waller's value for muscle, as that for the host as a whole, the ratio is 200/90, that is 2·2. The numerical coincidence is probably accidental, but it suggests that there may be, within limits, an adaptation of the organism to its surroundings, such that its electrical conductivity is always the greater.

4. *The Influence of Unidirectional Currents.*

On Water.—In the experiments about to be described all possible care was taken to control the temperature rise consequent upon the passage of the current. With the exception of those on the influence of alternating current on milk, the temperature of the liquid did not rise above 30° C. In the case of water a long and narrow form of sterilising cell was used, to keep the cell cool and at the same time to avoid the influence of any gas liberated at the electrodes when using direct current. Two No. 1 microscope cover-slips, each 2·5 cm. wide and 9 cm. long, were cemented together with paraffin wax to form a **V** trough 0·15 cm. wide, open at the top. Narrow strips of platinum foil were inserted at each end, the greatest distance between them being 4·5 cm. Even with the highest unidirectional pressures used, *i.e.* 480 volts, across the cell, and a current of 0·5 ampère per square centimetre in it, the fine bubbles of gas which escaped slowly from the electrodes could not be traced more than 0·3 cm. on the surface towards the centre of the cell. The stream of cooling water was on a level with that inside. The resistance between the poles with tap water in the cell was about 50,000 ohms. Quantities of $\frac{1}{2}$ c.c. of an emulsion of *B. coli communis* in non-sterilised tap water were introduced into the trough and exposed to a voltage gradient of 130 volts per centimetre for various intervals of time. With young fresh cultures an exposure of one minute caused slight but perceptible diminution in the number of colonies on a Petri dish culture compared with a control plate.

An exposure to direct current for five hours at a voltage gradient of 210 per centimetre and a current density of 0·3 ampère per square centimetre reduced the colonies in a ratio approaching 100 to 1. After 24 hours' exposure one colony developed, the control plate having a growth too dense to be counted with certainty.

The most efficient form of cell for use with direct current is one in which oxygen liberated at the positive pole bubbles through the liquid in escaping. For this purpose a cell with a short distance between pole plates placed in a horizontal plane in the liquid is convenient, taking a large current at low

voltage. The effect is similar to that produced by the passage of ozone through water, and being chemical rather than electrical is not considered here in detail. It provides, however, an effective means of sterilising potable water, using carbon electrodes, which might be of service where electrical power can be had at low rates.

On Milk.—In order next to examine the influence of direct current on milk, and as before to keep the gases at the electrodes from the central portion, a glass cell was made consisting of two circular pole-pits 4 cm. diameter, joined by a tube 1·5 cm. diameter. Flat platinum foil electrodes were used, the distance between them being 10 cm. Filled with fresh milk and connected to a 100-volt supply from secondary cells, a current of 0·15 ampère passed. The current density at the poles was then 0·03, and at the centre of the connecting tube 0·1 ampère per square centimetre. After a few minutes the milk in the neighbourhood of the positive terminal began to curdle, whilst that at the negative pole did not, though the surface became covered with a fine froth. After a quarter of an hour the milk in the positive pole-pit was a complete mass of hard curds, that at the negative a yellowish whey with no sign of curdling. In the centre tube the milk remained fresh and sweet to the taste; the taste of the curdled milk was strongly acid, and of the whey unpleasantly metallic.

These effects were due to direct ionisation, not to the passage of the current, or to the gases liberated, for on passing oxygen or hydrogen from storage cylinders for long periods through milk no curdling or separation resulted, and the milk in the centre tube carried the whole of the current without change, even with 500 volts across the cell. The formation of curds at the positive pole is in agreement with Hardy's conclusion* that coagulation is set up by contact with ions of the opposite sign to that of the liquid. In the present case the negative charge, though this is not so uniformly distributed as in blood cells, can be directly observed under the microscope, using a thin layer of milk and a strong electric field.†

These results show that unidirectional currents can be passed through milk without curdling it except quite near to the electrodes. As a practical process of sterilisation this would, however, be very inefficient on account of the large proportion wasted, and to attempt it at all, voltages of the order of 1000 to 2000 would have to be employed.

* See Whetham's 'Theory of Solution,' p. 399.

† See 'Roy. Soc. Proc.,' 1910, B, vol. 82, p. 638, 2, for the method.

5. *The Sterilisation of Water by Alternating Currents.*

Several observers working with weak current densities have stated that low frequency alternating currents do not affect bacteria,* and there do not appear to be any recorded cases of sterilisation by them other than of d'Arsonval and Charrin,† who found that *B. pyocyaneus* in a flask of liquid placed in the core of a coil carrying an alternating current lost its chromogenic power after 20 minutes' exposure to the induced magnetic field. Whether this was owing to the weak eddy currents set up in the liquid or to the action of the field was not determined. It is, however, improbable, in view of the high current densities required to produce marked effects, that the necessarily feeble eddy currents could have been the cause, which must rather be regarded as a direct action of the magnetic field upon the molecular structure of the cell contents of the particular organisms used. Strong alternating magnetic fields do not appear, from a few trials, to have any characteristic effect on bacteria in general. In making comparative experimental trials of the rate of sterilisation in this way, it is very necessary to use bacteria from the same culture, if possible from the same colony, both on account of the variation of the conductivity discussed in the next section, and of a difference found between bacteria from active and poor growths in their rate of sterilisation by electric currents. *B. coli communis*, many times sub-cultured, was exposed to an alternating current at a frequency of 80 per second and at a constant pressure gradient of 65 volts per centimetre in common salt solution having a resistance of 50 ohms per centimetre cube, in one of 200 ohms resistivity, and in one of 500 ohms. They were each exposed for three hours. The ratios of the number of colonies per unit area on the control plates to that on the exposed plates were respectively 150, 11·0, and 17·5. The rate of sterilisation in this case of constant voltage therefore falls rapidly as the resistance increases. The ratio of the reduction ratio to the current is the same in the first and last of these. The resistance of the bacteria was not measured in every case, but may be taken to be between 35 and 60 ohms per centimetre cube.

If, instead of having the same voltage gradient in each trial, the current-density is kept constant, results are obtained which show very clearly the greater influence of higher voltages. Exposures were made in 50, 200, and 1400 ohms solutions, with a current-density of 0·3 ampère per square centimetre in each case. The reduction ratios were respectively 9, 13, and 26. The bactericidal effect, therefore, does not depend only upon the

* Zeit ('Journ. Amer. Med. Assoc.,' Nov., 1910) found that weak alternating currents favoured growth.

† 'Comptes Rendus de la Soc. de Biol.,' 1893, p. 467.

quantity of electricity passing, but also on the influence of the field, which, though rapidly alternating, may, when high, cause more ionic movement through the cell walls of the organisms, or may act directly by breaking up their protoplasm.

The voltage gradient used in the later experiments approached unity in electrostatic measure. The force on a charge e ($4{\cdot}6 \times 10^{-10}$ E.S.U.) has the same arithmetical value as e in dynes, in unit field. This gives, assuming one such charge upon a section of 3×10^{-8} cm. diameter, an average molecular diameter, a stress of 635 grm. per square centimetre, which is enough, when rapidly reversed, to mechanically disintegrate most soft organic tissues, and presumably protoplasm.

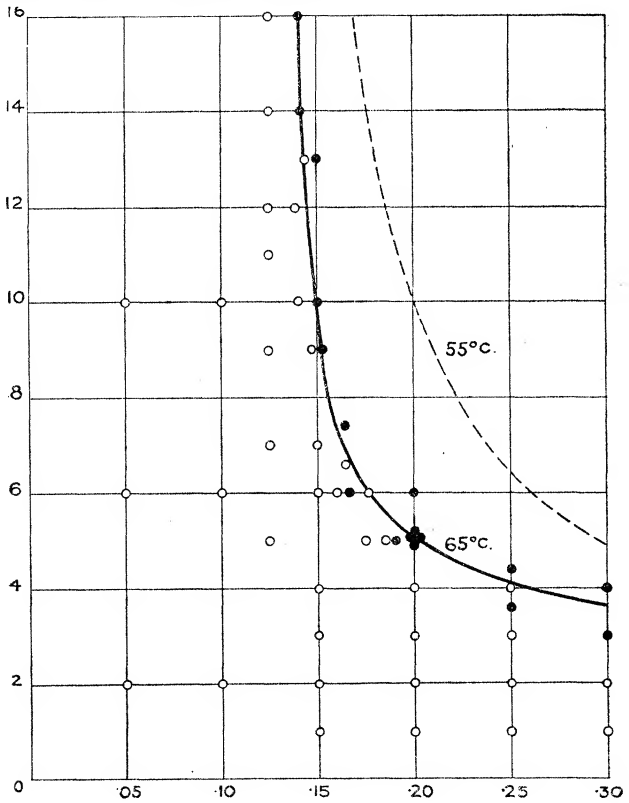
That it is possible to sterilise water by alternating currents at high voltage gradient and current density was shown by exposure for 19 hours at a voltage gradient of 150 per centimetre and a current density of 0·3 ampère per square centimetre. One colony developed as compared with a dense growth on the control plate. A comparison of the effects of direct and alternating current when precautions are taken to avoid the influence of electrolytic products shows that they are very similar. The conditions as to length and section of cell and to constant cooling must be observed.

The results in tap-water were so little different from those in weak salt solutions that the latter may be taken as representative of the degree of sterilisation in tap-water. The effect of time of exposure in the case of *B. acidi lactici* was examined by comparing plates sown with emulsion after 4, 10, and 20 minutes' passage of the current through it, with a control plate. The numbers of colonies are respectively 8000, 300, and 20, the growth in the control entirely covering the agar. This organism is therefore more sensitive to the current than *B. coli communis*. Later results with older cultures do not show so marked a difference, though it is always similar. The chief interest of this lies in the fact that with a current density of 0·5 ampère per square centimetre in cold water, 20 minutes does not cause complete sterilisation, whereas with new milk a shorter exposure does so. One reason for this, apart from heating and cooling, may be that in the latter case the bacteria were just beginning to grow, and were therefore more sensitive to the influence of the current.

6. *The Sterilisation of Milk by Alternating Current.*

For the purpose of exposing milk to alternating currents two large platinum crucibles were arranged, one inside the other, to form a cell, the distance between them at the bottom being 0·7 cm. The interspace could be filled through a hole in the ebonite cap with a known quantity of liquid.

A thermometer was afterwards inserted, and could be readily removed to take samples with a pipette. It was found necessary, on account of the heat produced by the passage of the current, to pack the outer crucible in ice, or, when the stronger currents were used, in a freezing mixture. The temperature was never allowed to rise above 65° C. in one set of trials or 55° C. in another. Working at the lower current densities it was possible to prevent the temperature exceeding the above limits for the whole time of exposure, without stopping the current; but with the higher currents this could not be done, and the time at 0·3 ampère per square centimetre, for example, of three to four minutes, was made up of half-minute runs with the same time for cooling. About 70 exposures were made, of which 55 are given for the 65° C. limit. Cultures were taken as sterile when they showed no growth after 24 hours' incubation at 37° C.



The results given previously of prolonged exposure to alternating currents at current densities of the same order as the above prove that sterilisation obtained by a few minutes' exposure, accompanied by rapid changes of temperature, must be regarded as thermal rather than electrical

in origin. It will, however, be seen that the form of the curve follows closely a rectangular hyperbola with a vertical axis displaced to about 0·05 ampère per square centimetre. There is, according to this, a current density at which no sterilisation occurs, however prolonged the exposure, which may explain Zeit's results, the warming action of the current encouraging growth. On the other hand, the fact that the curve is hyperbolic in contour would suggest that the result depends in some measure upon the quantity of electricity passed through the liquid, since this is the same for each point on the curve, if reckoned from the displaced vertical axis. It is probable that the ultimate cause of the results recorded here is not simple, but is in part thermal, and in part direct electrical action upon the molecular structure of the organism. That it is largely thermal is shown by the fact that longer time is required for sterilisation when the temperature is kept at a lower maximum. On the other hand, if it were entirely thermal, the time should be inversely proportional to the square of the current, which is not the case under the conditions of the experiment.

7. *The Action of Ultra-violet Light on Bacteria.*

The results of Sections 4, 5, 6, show that there is not a wide difference between the bactericidal influence of direct and alternating currents when the frequency of the latter is low. When, however, bacteria are exposed to electrical oscillations at their highest possible frequency, namely, that of ultra-violet light, the power required for sterilisation is so small that the result can only be caused by selective absorption of energy, either by the organism as a whole, or by its molecular structure. Exposure of *B. typhosus* in a thin hanging drop of water to strong polarised ultra-violet light causes no marked orientation, which might be expected to occur if the resonance were with the cell as a whole, for the free period of electrical oscillation on a rod is not the same longitudinally and transversely, and the bacillus would be forced, as it is in lower frequency currents, into such a position that the energy absorbed would be greatest. Under favourable conditions, with bacteria fresh from the animal, feeble though clear orientative response to the stopping and starting of polarised ultra-violet light has been obtained, but from the jerky type of movement, distinct from Brownian movement, it would appear to have been derived from stimulus of the flagella rather than to be an orientation by electromechanical forces. The bactericidal maximum found by Marshall Ward was at a wave-length of 4300 tenth metres, corresponding to a frequency of 7×10^{14}, in the low violet. If another maximum should ever be found near a wave-length of 2730, it would clearly point to the action being molecular. The frequency of rotation of an electron doublet

in an atom is of the order* 33×10^{14} a second. An electric charge rotating in an orbit in an alternating field of force is accelerated when the frequency of the latter agrees with, or is an odd sub-multiple of, the frequency of rotation. Thus a rotating electric charge in an atom would be eventually split off by resonance when the alternating field had a frequency of 11×10^{14}, corresponding to the third sub-multiple, or $6{\cdot}6 \times 10^{14}$, the fifth; this is the lower limit of the violet part of the spectrum, at which the bactericidal effect ceases. It is now suggested that Ward's lower maximum of 7×10^{14} may be the result of resonance with the fifth sub-multiple. The occurrence of another maximum at the higher frequency—which should be more clearly marked—would definitely decide this and the nature of the whole effect.

8. *Summary and Conclusion.*

The electrical conductivity of bacteria can be measured by observing their orientation when an electric current is passed through a liquid containing them. The values found range from 35 to 350 ohms per centimetre cube, and depend upon the nature and state of the culture medium. The results of sub-culturing are found to be that the conductivity of the bacteria increases at each step, reaching a steady value at about the fourth sub-culture on agar. Water containing added *B. coli communis* can be completely sterilised by direct currents in several hours at 0·3 ampère per square centimetre. Alternating currents sterilise water nearly, if not quite, as well as direct currents having the same current density. In order to obtain well-marked and constant results, it is necessary to use current densities of the order of 0·3 ampère per square centimetre, and to have a form of cell with a thin film of liquid which can be readily cooled. Milk is curdled by direct current at the positive pole and thinned at the negative pole. It can be sterilised, without "skin" forming, by the passage of alternating current through it, this being largely thermal. The cause of the bactericidal action of light is suggested to be syntony between it and the frequency of electronic movement in the protoplasm.

For the rapid sterilisation of liquids in bulk, such as sewage or potable water, the use of an ozone spray is to be preferred to direct electrical action. When, however, it is required to control bacterial growth in liquids over long periods without change of temperature it can be done by the passage of alternating electric current, or of direct current where electrolytic effects are not important. In either case, in order to obtain marked bactericidal effect it

* See W. Sutherland, 'Phil. Mag.,' Sept., 1901, Series 6, vol. 2, p. 273, and J. H. Jeans, *ibid.*, Nov., 1910, vol. 1, p. 422.

is necessary to work at such high current-densities that external cooling is required to control the temperature of the cell.

The preliminary investigation of the conductivity of bacteria and their behaviour in ultra-violet light was made in the Thompson-Yates Laboratories of the University of Liverpool in the summer of 1901. The author is in particular indebted to the late Sir Rubert Boyce for instruction and encouragement in the earlier work, and to Professor Hutchens, of the University of Durham College of Medicine, in the later stages.

An Investigation into the Life-history of Cladothrix dichotoma (*Cohn*).

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[Plate 8.]

The name *Cladothrix dichotoma* was first applied to this organism by Cohn in 1873. In 1875 he also founded the genus *Streptothrix* to include an organism (*S. Foersteri*) which differed from *Cladothrix* mainly in the possession of a mycelial habit. In 1887 the genus *Actinomyces* was also instituted by the same writer, to include the newly discovered *A. bovis*. Whatever may be the value of the distinction made by Cohn between *Streptothrix* and *Actinomyces*, there is no doubt whatever about the clearness of the line of separation which he set up between these genera and *Cladothrix*. Unfortunately, later writers have used the term *Cladothrix* to indicate not only the only organism belonging to the group, but also species belonging to *Streptothrix*. As examples may be mentioned the organism described by Cienkowski (3) in 1877, which he describes as having a branched mycelial habit. The same mistake was made by Winter (21) in 1884. Influenced, doubtless, by these descriptions, Macé (14) in 1884 denied the separate identity of *Streptothrix* and *Cladothrix*. In his work he describes the characteristics of *Cladothrix*, and gives, under this name, precisely those defined by Cohn as belonging to the genus *Streptothrix*. The confusion by this time had become fixed, and we find the same mistake in later writers. Thus Günther and Rullmann (10), in 1896, describe as *Cladothrix odorifera* what is obviously a *Streptothrix*. Again, Acosta and